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Pesticide & Fertilizer Management

AFREC FINAL REPORT

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PROJECT DESCRIPTION: Phosphorus availability and its relationship to sorption maximum and sorption strength

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Abstract

Understanding soil phosphorus (P) and what soil properties affect P availability in soil is crucial to improving P management in land used for agriculture. Over the last century soil P has been the focus of innumerous scientific articles, which has helped in the development of current strategies for P management. Currently, two different mechanisms are used to study soil P, one focus on soil P buffer capacity (PBC) and the other focus on the parameters sorption maximum and sorption strength. Both mechanisms are extremely important in developing a good understanding of P dynamics in soils. However, there is no research in the literature that has provided a link between the two mechanisms. In addition, there is no research that has reported what soil property/properties controls soil PBC and the sorption maximum and sorption strength. Although some researchers have hypothesis, there are no concrete evidences that prove or disprove any of those hypothesis. Therefore, the objective of this research was to try and relate the soil PBC to sorption maximum and sorption strength and also determine which soil property/properties controls these parameters. This research project has been broken into two separate studies because of the funding strategy used by AFREC. This section dealt with the PBC, while the on going research deals with the sorption parameters.

Introduction

Researchers have used two different concepts to study the chemistry of phosphorus (P) in soils. One is related to the P buffer capacity (PBC) and the second is related to the sorption maximum and sorption strength. The PBC is defined as the amount of inorganic P in mg kg^{-1} soil (ppm) required to increase soil test P by 1 ppm. The greater the PBC value of a soil is, the greater the amount of P that must be added to increase the STP by unit. Beckett and White (1964), used the quantity (Q) and intensity (I) relation as a measure of soil PBC, where dQ/dI = PBC. The Q parameter, represents the amount of P in reserve, bound to the labile pool in the soil. This parameter can be measured, for example, by chemical extraction or by isotopic exchange, among other methods. The I parameter, is the chemical potential of orthophosphate, or phosphate activity in the soil. It can be estimated by measuring the P concentration in a solution that has been equilibrated with the soil for a determined amount of time (Beckett and White, 1964). These authors have reported a strong linear relationship between Q and I for several soils. This suggests that a given soil has a unique PBC value regardless of the value for Q or I, and the PBC differs between different soils. However, the authors did not report any data on the effects of initial soil P status on soil PBC neither what soil property/properties determines or controls the PBC. Other authors have used different mechanisms to estimate soil PBC. For example, Ransome (1988) calculated PBC by applying increasing amounts of P to several soils. After a certain equilibration time *t,* STP was determined and regressed on the P application rates used in the study. The PBC value was then calculated by taking the reciprocal of the slope of that regression line as follows:

$$PBC = \frac{1}{\alpha}\text{, where } \alpha = \left(\frac{\partial STP}{\partial PA}\right)_{\text{sp}}\text{, therefore } PBC = \left(\frac{\partial PA}{\partial STP}\right)_{\text{sp}} \qquad [1]$$

where α is the slope of the line that describes the increase in STP as a function of P application rate (PA). The partial derivative indicates that the source of P (sp) is being held constant and rate is the only variable allowed to change. Figure 1 shows this relationship for a hypothetical soil, though it was generated from real data. Researchers have reported PBC values ranging from 1 to more than 8 for various soils (Griffin et al., 2003; Laboski and Lamb, 2003). However, little is understood about what soil property/properties regulates the soil PBC.

The second concept regards the sorption maximum and sorption strength and those properties are related to how much P can adsorb onto soil particles (sorption maximum) and how strong (sorption strength) the chemical bond between the soil particles and the P is. The sorption maximum and sorption strength of soils are calculated by isotherm experiments. Isotherm experiments are performed by equilibrating a given amount of soil with solutions of increasing P concentrations and then determining the amount of P left in the solution after equilibrium is attained. The amount of P left in solution after equilibrium is strongly related to the amount of P initially in solution. Figure 2 shows this relationship for a hypothetical soil, though it was generated from real data. Depending on the soil type the sorption maximum can range from 100 to 1,000 ppm, whereas the sorption strength can range from 0.1 to 0.7 (Laboski and Lamb 2004; Sidique and Robinson, 2003). The higher the value for the sorption maximum is the more P can be held in the soil, and the higher the sorption strength the stronger the chemical bond between the particle and the P is.

The soil PBC and the sorption maximum and sorption strength are soil parameters that are well understood individually. However, there is no research that has shown how the two parameters are related. In addition, there is no research that has demonstrated what soil property/properties controls each parameter. Another gap in the scientific knowledge appears when the two properties are plotted on the same scale. For example, Figure 3 shows a theoretical plot where both parameters were plotted as a function of P added in ppm. The zone called "Unexplored region" represents an area in P adsorption/availability that has not been studied before. Understanding this "Unexplored region" is the key to making the connection between the soil PBC and sorption maximum and strength of soils. Because soil PBC relates what fraction of the applied P will bind to soil particles and the isotherm relates how much and how strong P can bind to soils, connecting the two could help improve P management in areas that might be potentially sensitive to P application. Furthermore, this could also lead to better P management in any land that receives P as inorganic fertilizer for crop production.

Objectives:

The objective of this research was to:

i) Determine the soil PBC in the soils collected for the study.

Material and Methods:

Thirty-three soils samples were used in this study. Samples were collected from areas under agricultural use from different regions in the United States. There were 26 soils collected from MN, three from Texas, one from Iowa, and three from Wisconsin. Table 1 lists the soils and PBC values of each soil as determined using the Bray-1, Olsen, Mehlich-3 and water extracts.

After soil collection, soils were air dried and sieved through a 2-mm sieve to remove large size particles and stored in plastic buckets until needed to the study. The PBC of each soil was determined using an incubation study. In the incubation study, a subsample of each soil (50 grams) were mixed with increasing amounts of fertilizer P (0 to 12000 mg P kg^{-1}) and incubated at 25°C for 8 weeks (time required for equilibrium between fertilizer P and soil). During the incubation study soil samples were kept at a water content ranging from 40 to 60% of field capacity. Samples were weighed on a weekly basis and deionized water was added to maintain the desired moisture content level. At the end of the 8 weeks, samples were air-dried and the soil samples were extracted using the Bray-1, Olsen, water, and Mehlich-3 methods to determine the extractable P. Extracts were analyzed using inductively couples plasma optical emission spectrometry (ICP-OES).

Results

Figure 1 shows the response observed in the increase in soil test P (STP) for the Zimmerman soil as determined by the Bray-1. The linear response in the increase in STP as a function of P application rate observed for the Zimmerman soil was similar to the increase in STP observed for all other soils using the Bray-1 test.

Table 1 shows the PBC values for all soils as determined by the Bray-1, Olsen, Water, and Mehlich-3 extractants. PBC values estimated using the Bray-1 test ranged between 1.2 and 2.9; the Olsen it ranged between 2.1 and 8.1; Mehlich-3 ranged between 1.2 and 11.6; and for the water it ranged between 1.8 and 9.7 (Table 1). Within each extractant, the mean value and median we very close between all soils. For the mean and median values for the Bray-1 extractant was 2.1 and 2.0; for the Olsen they were 4.2 and 4.0; for the Mehlich-3 they were 2.3 and 2.0; and for the Water they were 3.9 and 3.7, respectively.

The values for the PBC observed in this study are coherent with other studies published in the literature. However, the most important findings in this research is the fact that the increase in soil test P was linear for all rates applied, no matter how high there were.

The next phase of the study will help us make the correlations needed to provide a complete understanding of the soil properties that control the behavior of P in soils.

References

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Table 1. Soil phosphorus buffer coefficient (PBC) for all soils used in the study. Soil PBC is a unitless property of soils.

Soil	Bray-1	Olsen	Mehlich-3	Water
	Soil Phosphorus Buffer Capacity (PBC)			
Amarillo	1.49	3.34	1.61	3.24
Barnes	2.01	3.91	2.31	3.89
Canisteo	2.75	2.76	2.34	9.69
Clarion	2.58	3.59	2.39	3.40
Colvin	2.00	4.57	1.49	5.48
Cordova	1.74	4.70	1.83	3.36
Estereville	1.96	6.51	2.01	3.22
Fargo	2.35	5.49	2.46	5.53
Formadale	1.73	4.47	1.33	2.88
Gunclub	2.40	3.80	1.51	4.50
Hegne	2.46	4.01	1.78	3.25
Hubbard	1.85	2.88	1.67	2.78
Iowa	1.75	4.92	1.27	4.20
Lester	1.85	2.07	2.80	3.09
Mt Carroll	2.77	5.92	2.23	4.00
Nicollet	2.48	4.39	2.55	3.90
Normania	2.29	3.28	2.44	3.92
Okaboji	2.96	4.84	2.21	6.13
Pella	1.17	2.59	1.21	2.55
Pierz	1.36	3.39	1.84	2.74
Pullman	2.20	4.17	11.55	3.34
Randall	2.23	3.66	2.02	4.49
Seaton	1.83	3.67	2.20	3.13
St. Charles	1.70	3.95	1.81	3.76
Storden	2.06	5.54	2.45	3.65
Tara	1.73	3.22	1.88	3.48
Verndale	1.36	2.48	1.16	1.80
Ves	2.49	6.09	2.30	5.50
Walter	1.53	4.29	1.50	3.78
Waukegan	2.65	8.14	2.49	3.65
Webster	1.95	4.40	2.37	3.24
Wheatville	2.94	3.97	2.12	5.40
Zimmerman	1.40	2.56	1.50	2.26

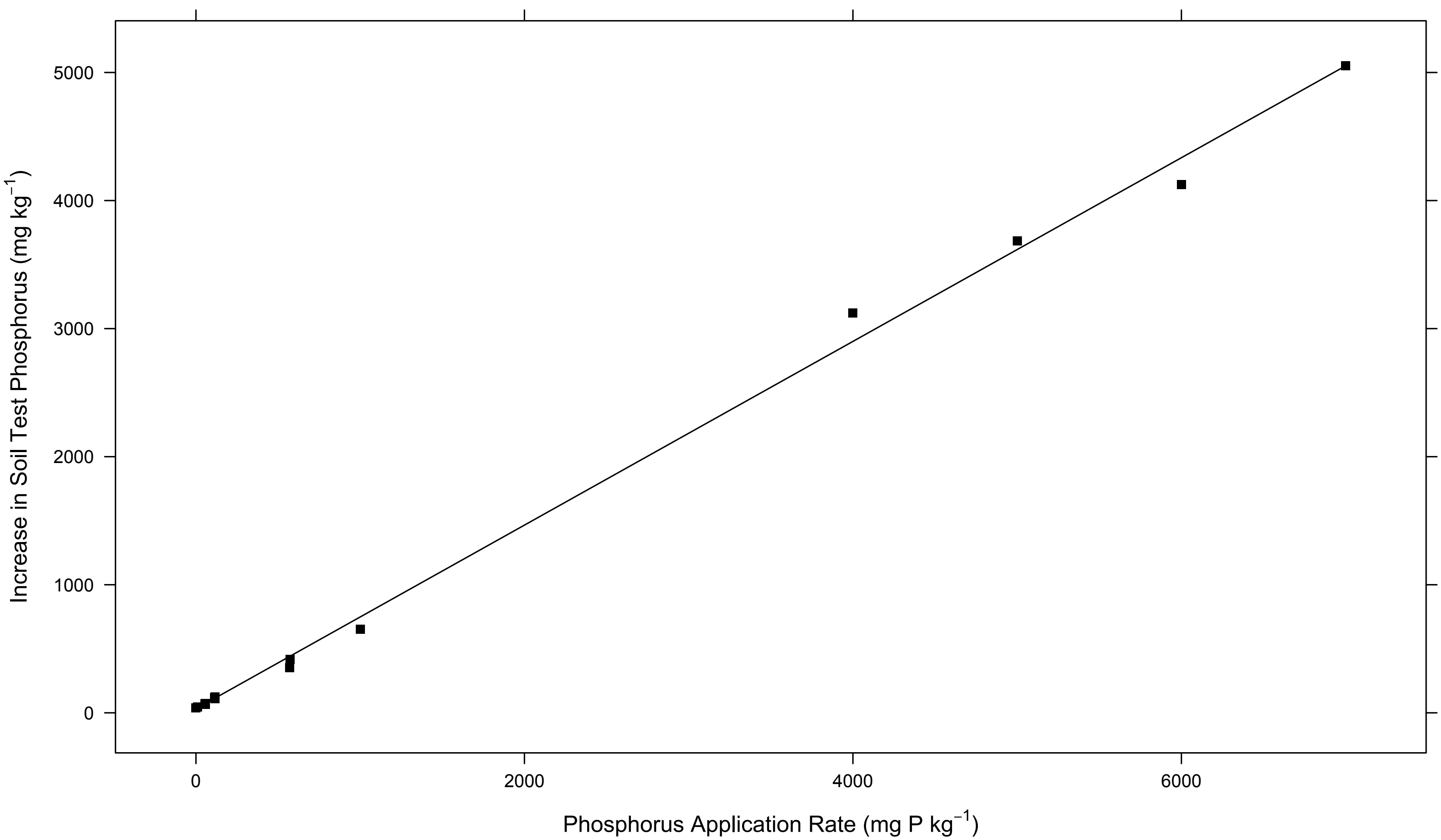

Figure 1. Increase in soil test phosphorus as a function of phosphorus application rate for the Zimmerman soil.